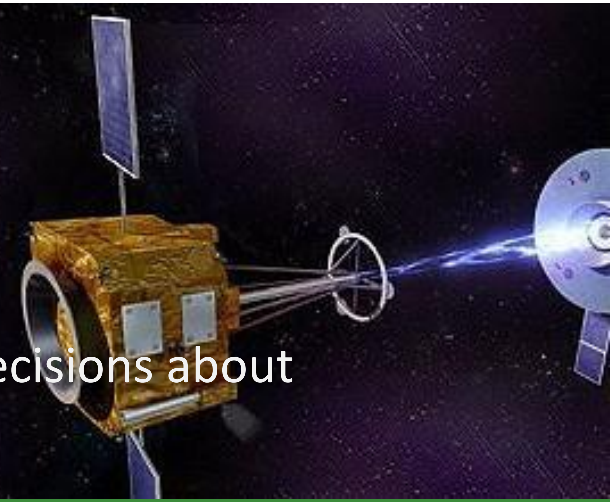
December 7, 2012



Environmental Life Cycle Criteria for Making Decisions about **GREEN** versus **TOXIC** Propellant Selections

10th Annual Workshop on Environment and Alternative Energy

Christyl C. Johnson
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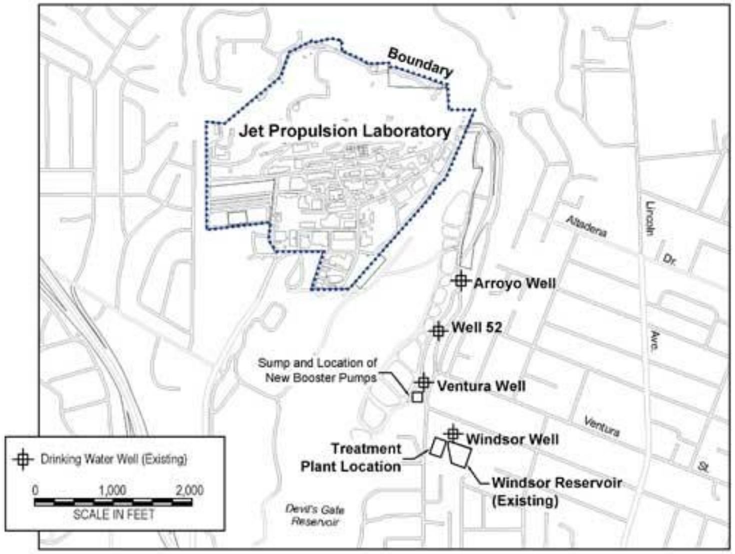
Director of Engineering

Our Nation’s History with Propellants

Toxic Propellant Risks/Danger



Toxic Propellant Risks/Danger

Columbia Accident
February 1, 2003

“Green” Propellants Needed

NASA Options Study Cost Analysis

Propellant Options

- Option 1: Constellation Baseline (Hypergols)
- Option 2: Lox/Methane on CEV SM and LSAM Ascent Stage
  - Option 2a: Baseline Lox/Methane
  - Option 2b: Lox/Methane and Hypergol Dual Development Program through PDR, Drop Hypergols at PDR
  - Option 2b+: Block Upgrade CEV SM to Lox/Methane for Lunar Missions, Use Lox/Methane for LSAM Ascent Stage
- Option 3: Lox/LH2 on CEV SM and LSAM Ascent Stage
  - Option 3a: Baseline Lox/LH2
  - Option 3b: Lox/LH2 and Hypergol Dual Development Program through PDR, Drop Hypergols at PDR
  - Option 3b+: Block Upgrade CEV SM to Lox/LH2 for Lunar Missions, Use Lox/LH2 for LSAM Ascent Stage
- Option 4: Mixed Hypergolic and Alternative Propellants
  - Option 4a: Hypergolic SM, and LSAM RCS; Lox/LH2 LSAM Ascent Stage Main Engine
  - Option 4b: Hypergolic Integrated SM and LOX/Methane Integrated LSAM Ascent Stage Main Engine

Cost Methodologies

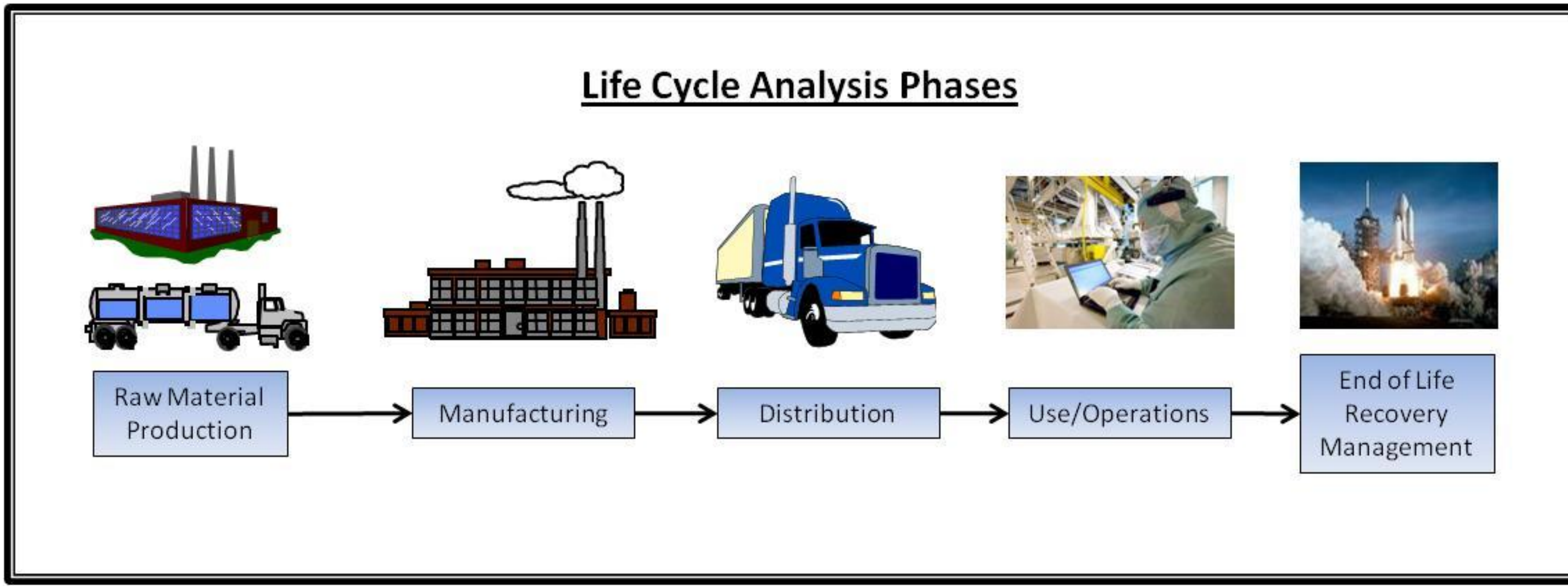
Cost Element	Method
CEV SM DDT&E & Production -Propulsion Subsystem -All Other Subsystems	 Component Cost Model ARCOM
LSAM DDT&E & Production -Ascent Stage Propulsion Subsystem -All Other Subsystems	 Component Cost Model NAFCOM
EDS DDT&E & Production	NAFCOM
Ground Processing	KSC Bottoms-up Assessment
Technology Development	Combination of Existing Contracts, Past Estimates, and Expert Option

Costs Compiled and Phased Using the SAIC Life Cycle Cost Integration Model

Decision:

Risk too great and return on investment not sufficient to support a commitment to wholesale investment in "green" technologies for propellant systems now

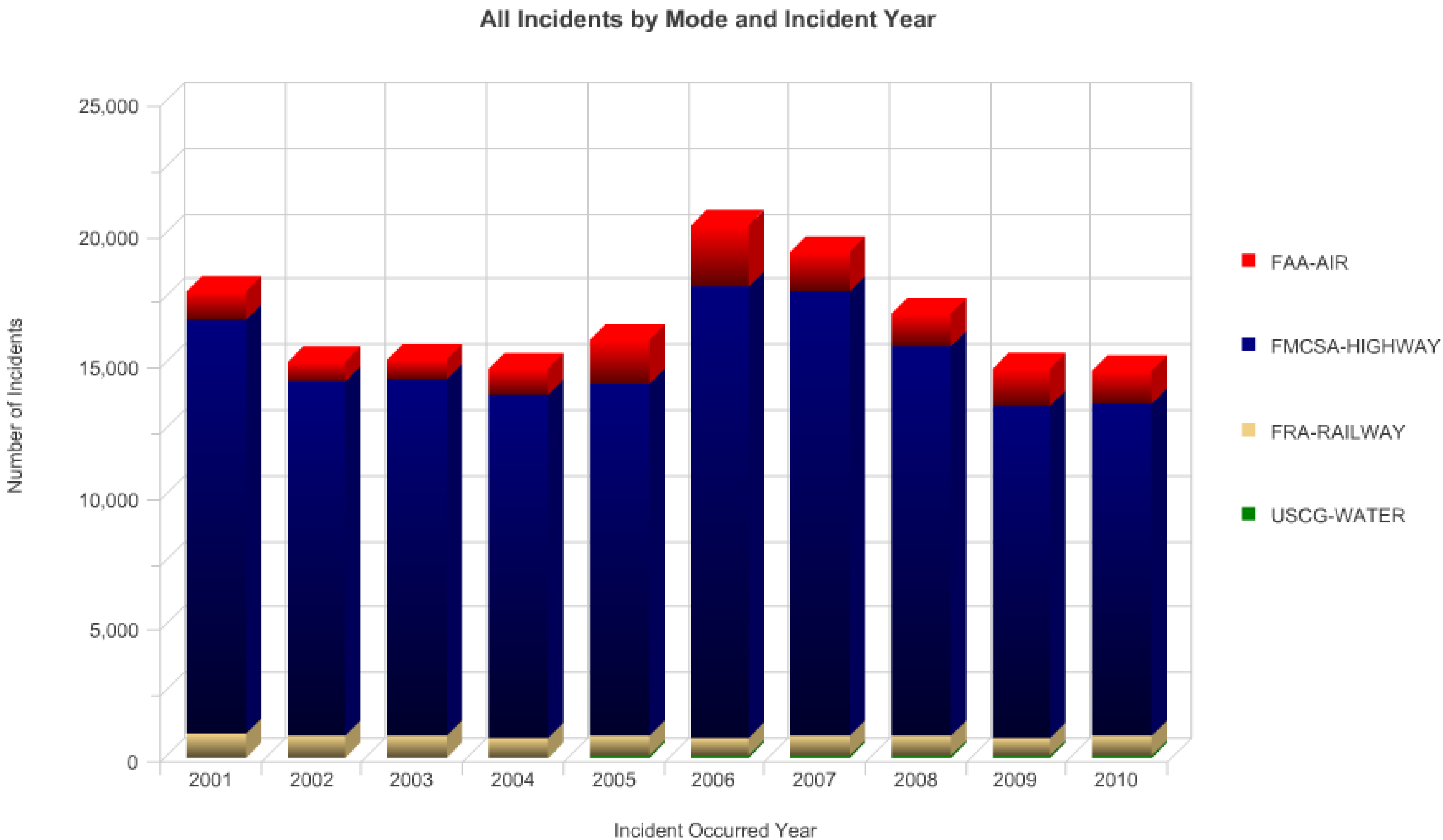
Life Cycle Analysis



Worker Exposure/ Occupational Safety Concerns

Case Study: Transportation Incidents

Hazardous Materials Transportation Incidents Happen Frequently



Source: U.S. Department of Transportation Hazmat Intelligence Portal, retrieved November 2011

Case Study: Transportation Incidents

Financial Costs of Hazardous Materials Transportation Incidents

Incidents By Mode and Incident Year

Mode Of Transportation	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Grand Total
FAA-AIR	1,083	732	750	993	1,654	2,406	1,556	1,278	1,356	1,293	**13,101**
FMCSA-HIGHWAY	15,804	13,502	13,594	13,068	13,461	17,162	16,930	14,804	12,730	12,645	**143,700**
FRA-RAILWAY	**899**	**870**	**802**	**765**	**745**	**703**	**753**	**749**	**643**	**751**	**7,680**
USCG-WATER	6	10	10	17	69	68	61	99	90	105	**535**
Grand Total	**17,792**	**15,114**	**15,156**	**14,843**	**15,929**	**20,339**	**19,300**	**16,930**	**14,819**	**14,794**	**165,016**

Damages By Mode and Incident Year

Mode Of Transportation	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Grand Total
FAA-AIR	$309K	$109K	$100K	$188K	$198K	$671K	$88K	$191K	$708K	$20K	**$2,583,290**
FMCSA-HIGHWAY	$47.7M	$48.1M	$49.1M	$47.2M	$40.2M	$59.5M	$47.3M	$42.8M	$50.6M	$63.8M	**$496,233,940**
FRA-RAILWAY	**$21.2M**	**$9.75M**	**$4.13M**	**$13.9M**	**$15.5M**	**$10.7M**	**$27.3M**	**$8.03M**	**$17.5M**	**$7.36M**	**$135,466,997**
USCG-WATER	$147K	$248K2	$261K	$1.65M	$114K	$58.8K	$19,097	$138,350	$100,887	$574,103	**$3,316,416**
Grand Total	**$69.4M**	**$58.2M**	**$53.6M**	**$62.9M**	**$55.9M**	**$71.0M**	**$74.7M**	**$51.2M**	**$69.0M**	**$71.7M**	**$637,600,643**

Source: U.S. Department of Transportation Hazmat Intelligence Portal, retrieved November 2011

Railway Avg: $17638 per incident. Water Avg: $6199 per incident.
Highway Avg: $3453 per incident. Air Avg: $197 per incident

Case Study: Transportation Incidents

Human Costs of Hazardous Materials Transportation Incidents

Injuries By Mode and Incident Year *(people transporting or responding to incidents)*

Mode Of Transportation	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Grand Total
FAA-AIR	13	4	1	11	44	2	8	7	10	2	**102**
FMCSA-HIGHWAY	109	118	105	155	178	192	160	153	153	153	**1,476**
FRA-RAILWAY	**46**	**14**	**13**	**122**	**693**	**25**	**57**	**63**	**38**	**13**	**1,084**
USCG-WATER	0	0	0	0	0	15	3	0	0	2	**20**
Grand Total	**168**	**136**	**119**	**288**	**915**	**234**	**228**	**223**	**201**	**170**	**2,682**

Fatalities By Mode and Incident Year

Mode Of Transportation	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Grand Total
FAA-AIR	0	0	0	0	0	0	0	0	0	0	**0**
FMCSA-HIGHWAY	9	9	15	11	24	6	9	6	11	8	**108**
FRA-RAILWAY	**3**	**1**	**0**	**3**	**10**	**0**	**0**	**1**	**1**	**0**	**19**
USCG-WATER	0	0	0	0	0	0	0	3	0	0	**3**
Grand Total	**12**	**10**	**15**	**14**	**34**	**6**	**9**	**10**	**12**	**8**	**130**

Source: U.S. Department of Transportation Hazmat Intelligence Portal, retrieved November 2011

Railway Avg: 1 injury every 7.1 incidents and 1 fatality every 404 incidents

Water Avg: 1 injury every 27 incidents/1 fatality every 178 incidents.

Highway Avg: 1 injury every 97 incidents/1 fatality every 1330 incidents.

Air Avg: 1 injury every 128 incidents/0 fatalities every 13100 Incidents.

Case Study: SeaCliff Derailment

July 28, 1991 Rail Incident


A sulphuric acid spill due to a train derailment

- Train traveling on Southern Pacific line in Ventura County, CA derailed beneath Highway 101.
- A car carried **eighty 55 gallon containers of aqueous hydrazine.**
- **23 of the hydrazine drums (1265 gallons) ruptured or leaked.**
- Ventura County Fire/Environmental Health Departments responded.
- **Highway 101 was closed for 6 days.**
- Over **300 residents** of Seacliff Beach Colony located 100 feet away from the derailment were **evacuated** from their homes.
- **Rail worker was sickened** after inhaling fumes.
- Response was **stalled by confusion** – manifest met requirements but did not list chemical names, quantity, or container type.
- **49 homes were evacuated** for nearly a full week.

Case Study: SeaCliff Derailment

Final Cost: **$750,000+ (at least)**

- **$435,167** to Ventura County Fire Department
- **$200,000** split among Ventura/Oxnard Fire Depts & County Health Department
- Remainder to California EPA and other agencies
- **Legal Costs Unknown: 22 settlements** to Seacliff residents
  - 338 other claims rejected, most related to inconvenienced drivers.
  - A railway worker has also sued in relation to the incident.
- A derailment nearby involving the same company during the same two week period caused toxic chemicals to spill into the Sacramento river – the total resulting cost (including legal) was **over $44 Million.** *(pesticides – killed most wildlife within the vicinity)*

Environmental Life Cycle Costs

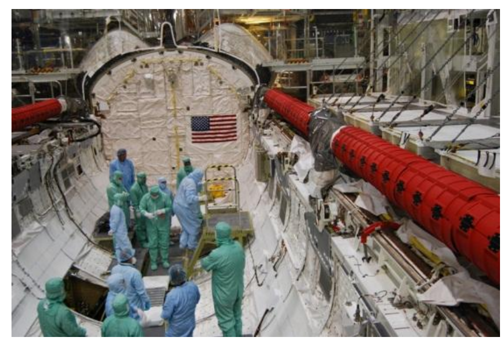
Must be factored into the Life Cycle Cost Analysis………

How do we determine which environmental parameters to include for future NASA decisions?

SITE VISITS – NASA (Kennedy /Wallops)

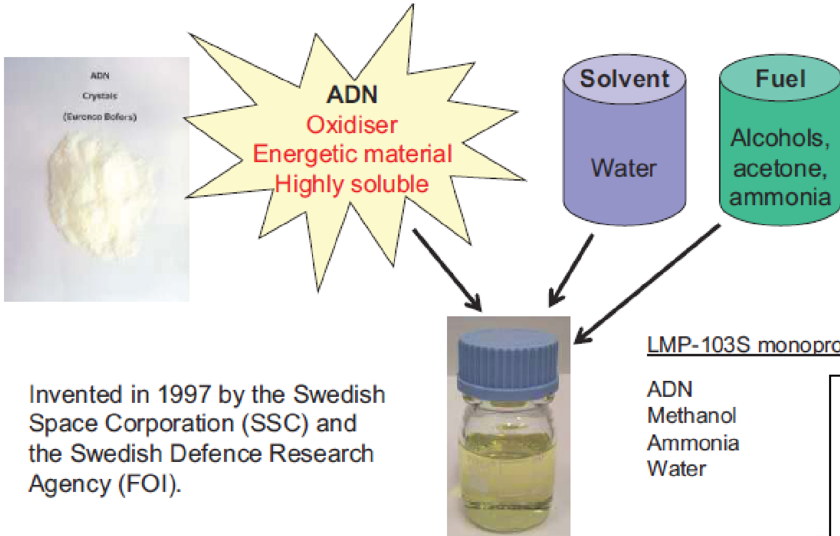
NASA's Wallops Flight Facility

NASA's Kennedy Space Flight Center



Ammonium Dinitramide (ADN)

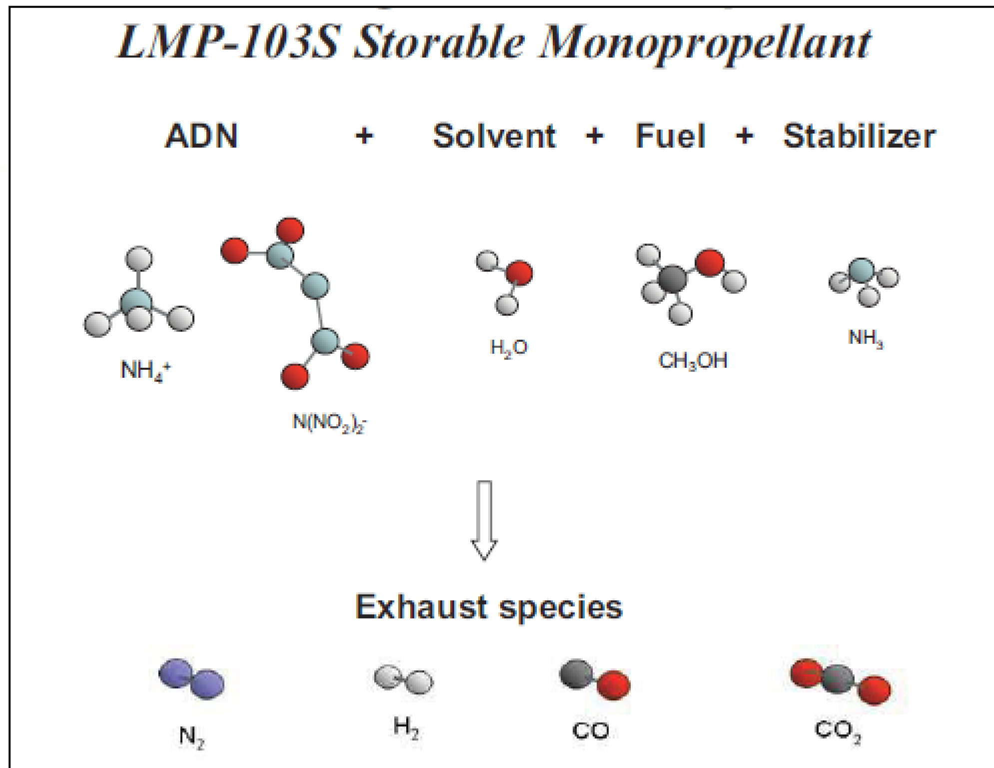
- Solid white salt
- No chlorine content
- High performance
- Readily soluble in water



Invented in 1997 by the Swedish Space Corporation (SSC) and the Swedish Defence Research Agency (FOI).

LMP-103S monopropellant:

ADN
Methanol
Ammonia
Water



$NH_4{\cdot}N(NO_2)_2$

SITE VISITS - Sweden

Environmental Cost Elements

ENVIRONMENTAL UNACCOUNTED FOR COST ELEMENTS	HYDRAZINE	HPGP
MANUFACTURING AND STORAGE		
A. General Safety Considerations:		
1. Safety training for all site personnel	40 hours minimum ($375/person + $70/person annually for mandatory refresher)	1 hour per facility/building
2. Medical monitoring	Annual Comprehensive Medical Exam	N/A (non-hazardous operation)
3. Hand-held communication devices for emergency and auxiliary use	Walkie Talkies (~$60/pair) Satellite Phones (~$1100 ea.)	N/A (non-hazardous operation)
B. Site Control and Access:		
1. Entrance to facility controlled by guard station	24 hours/day ($300K/yr or up to $3M to build new one)	N/A (non-hazardous operation)
2. Exclusion zone (no one allowed inside w/o specific need and training/certification)	Additional square footage, access control, and decontamination requirements (not quantified)	N/A (non-hazardous operation)
3. Contamination reduction zone	Additional square footage and decontamination requirements (not quantified)	N/A (non-hazardous operation)
C. Air Monitoring:		
1. Permanent air monitoring stations installed	Inside and around manufacturing facilities	Not required
2. Station monitoring	24 hours/day	Ammonia sensors are adequate (unmanned)
3. Calibration and maintenance of monitoring equipment	Calibration performed at the beginning of each work day	Regular intervals
4. Personal dosimeter badges		Not required

D. Personal Protective Equipment (PPE) for people in the storage tank area:		
1. If no leaks have occurred -	SCAPE suit required	
• Work coveralls (or use of SCAPE Suit)		Required
• Steel-toed boots		Not required
• Surgical glove		Required
• Hard hat		Not required
• Visor or Safety Glasses		Required
2. If there is an uncontained exposure to the hazardous material -	SCAPE suit required	Gas mask required in case of major leak
• Tyvek suits (or use of SCAPE Suit)		
• Steel-toed boots		
• Overboots		
• Inner and outer gloves		
• Hard hat		
• Respiratory protection		
E. Decontamination Procedures:		
1. Each individual must be decontaminated before leaving the exclusion zone		N/A (non-hazardous operation)
• Wash the outer PPE to remove gross contamination	SCAPE suit cleaning or disposal	N/A (non-hazardous operation)
• Removal and disposal of the PPE		Discard gloves only
• Shower prior to entry into any other part of the facility		Not required
• Washtubs, brushes, water, and citric acid must be available for decontamination		Not required
• Wash water must be collected and treated before discharge		N/A (non-hazardous operation)
• Used PPE's must be placed in numbered and labeled barrels to be stored onsite (non SCAPE PPEs)		N/A (non-hazardous operation)

Environmental Cost Elements

F. Storage		
1. Special storage containers for hazardous materials	DOT-4BW	Opaque plastic container acceptable
2. Special temperature control capability	Store at temps below 51 C (123 F).	Long-term storage: 10-50°C (50-122°F) Short-term storage: -5-70°C (41-156°F)
3. Special pressurized containers	Can be packaged only in Teflon high density polyethylene or stainless steel containing less than 0.5% molybdenum. Must use nitrogen blanket.	Plastic container with latching lid acceptable (not compatible with aluminum tanks)
SHIPPING/TRANSPORTATION		
A. Rail:		
1. Special transporter training/certification	FORBIDDEN	Yes
2. Special storage/shipping drums	N/A	UN 1.4S
B. Sea Vessels (Ship):		
1. Special transporter training/certification	Yes	Yes
2. Special storage/shipping drums	DOT-4BW	UN 1.4S
C. Air:	Commercial Passenger FORBIDDEN	Allowed on commercial passenger aircraft
1. Special transporter training/certification	N/A	Yes
2. Special storage/shipping drums	N/A	UN 1.4S
D. Public Highways:		
1. Hazmat Cargo tank trailers	Yes	No
2. Special drivers' certification	Yes	Yes
3. Transporter liability insurance	Yes	Yes
4. Special storage/shipping drums for smaller quantities	DOT-4BW	UN 1.4S

FACILITY OPERATIONS & MAINTENANCE		
1. Construction (to meet safety specifications)	Required	Required
2. Air scrubbers (installation & operation)	Required	Not required
3. Spill handling & disposal (catchment tanks)	Required	Required
4. Annual facility certifications & inspections	Required	Required
5. Mandatory safety personnel (fire, medical, etc.)	Required	N/A (non-hazardous operation)
6. A minimum of 2 people must be present during all hydrazine facility operations (2 additional people must be in SCAPE suits on standby during hazardous fueling operations)	Required	Not required
7. Fueling Operations:		
a. Safety requirements		
• Range safety personnel support	Required	Required
• Medical personnel	Required	N/A (non-hazardous operation)
• Fire personnel	Required	N/A (non-hazardous operation)
b. "Down time" of all launch campaign personnel not involved in hazardous fueling operations	Required	N/A (non-hazardous operation)
c. Ground support equipment refurbishment and preparation		
• Fueling cart decontamination	Req'd/Comprehensive	Limited
• Drum decontamination	Req'd/Comprehensive	Limited
• Replacement of facility spill catchment tanks (if necessary)	Req'd/Comprehensive	Limited

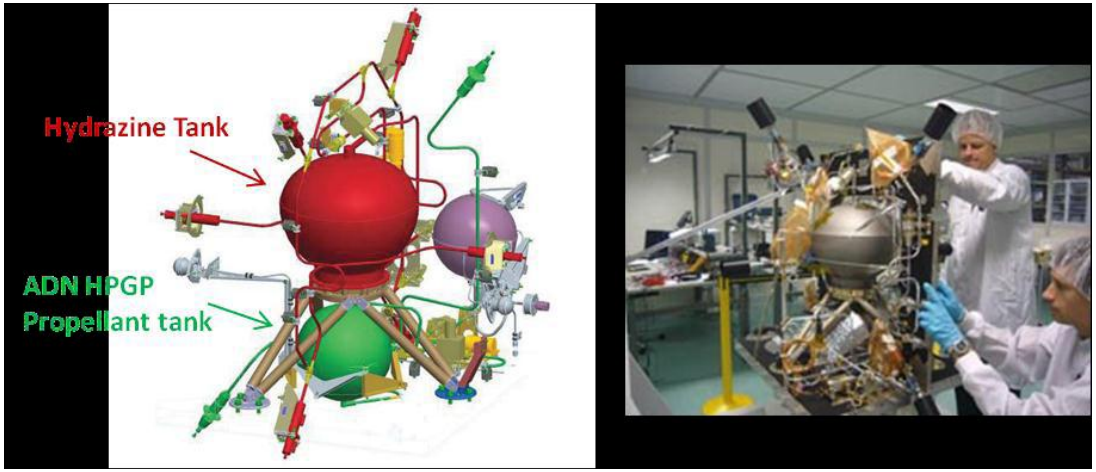
Environmental Cost Elements

END OF LIFE DISPOSAL		
A. Propellant End of Use:		
1. Disposal of contaminated objects	See pages 71-73	Flush with water (wastewater treated as non-toxic waste)
2. Disposal of residual propellant/waste		Controlled burn with absorbent
3. Propellant drum return	DOT-4BW	Non-hazardous
B. Facility Decommissioning:		
1. Hazard Reduction	See descriptions on pages 71-73	Not required
2. Liquid waste handling and disposal		Flush with water (wastewater treated as non-toxic waste)
3. Dismantling and demolition		Flush with water (wastewater treated as non-toxic waste)
4. Site restoration		Not required
- Decontamination and removal of equipment and subsequent revegetation of the grounds after demolition debris and solid wastes are removed		Not required
- Postclosure vegetation maintenance		Not required

CASE STUDY – PRISMA MISSION

MISSION OVERVIEW

- Demonstration mission focused on formation flying and rendezvous technology in space environment
- Swedish Space Corporation, Swedish National Space Board, OHB Sweden, German Aerospace Center (DLR), French National Space Center (CNES), and the Technical University of Denmark



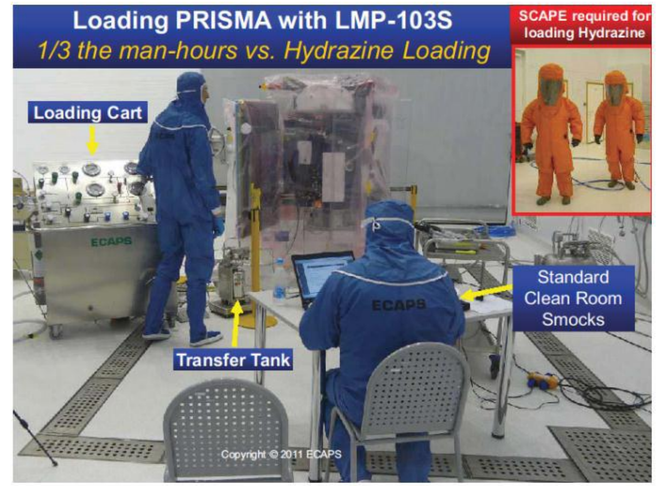
- Two spacecraft – Mango and Tango
- Mango has two monopropellant systems – a hydrazine baseline and a High Performance Green Propellant using LMP103 (ADN)

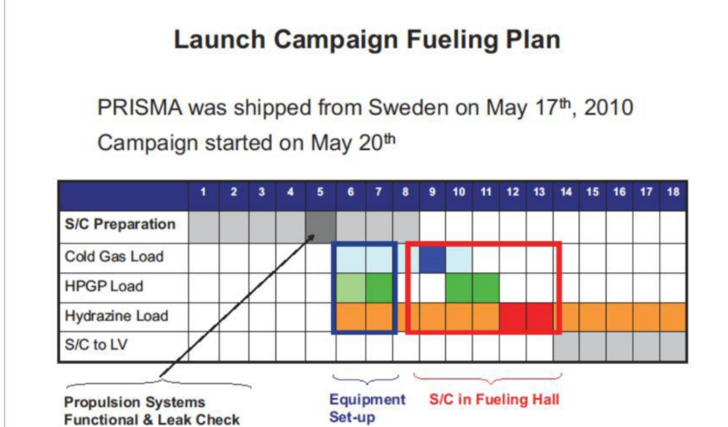
TRANSPORTATION OF PROPELLANT

- Prisma spacecraft and the HPGP propellant were flown by commercial aircraft from Sweden to the launch facility in Russia
- Hydrazine could not be shipped via aircraft, so it was transported from Germany to St. Petersburg on a ship, and then transported by truck to the Russian launch facility - months in advance of the launch campaign.

HANDLING AND OPERATIONS DURING LAUNCH CAMPAIGN

- SCAPE suits not required
- HPGP loading process took seven days with 2 specialists and 1 part-time technician
- Hydrazine loading took 14 days with 5 mission specialists and more than 20 support specialists (more than 3 times the manpower)
- Hydrazine waste – 8 gal of hydrazine, 105 gal of contaminated de-ionized water, and 18 gal isopropyl alcohol. Hazardous waste procedures had to be followed.
- HPGP waste – ¼ gal of propellant and ¾ gal of isopropyl alcohol/de-ionized water (considered non-toxic). Disposal of these wastes was provided at no charge because of the non-toxic classification





PRISMA Launch Campaign
Environmental Hazards

	Hydrazine	HPGP LMP-103S
PRISMA Campaign	470 kg toxic waste	3 kg non-toxic waste
	29 kg propellant waste	1 kg propellant waste

CASE STUDY – PRISMA MISSION

PRISMA HPGP to Hydrazine Cost Comparison

PHASE E - S/C Propellant Loading	HPGP	HYDRAZINE
Management, I/F & Config Control	€ 21,340	
Fueling Procedure	€ 12,371	
Range Safety Documents	€ 12,371	
Launch Site Visit, I/F & Range Safety Review	€ 6,186	
Travel and Subsistence	€ 1,546	
Crew Training and Cerification	€ 7,423	
Mgmt & Engineering Subtotal (as above)	**€ 61,237**	**€ 144,289**
GSE Referb & Prep	€ 37,113	€ 46,000
Launch Site Activities	€ 38,435	€ 139,754
Propellant and Propellant Shipping Cost	€ 21,031	€ 130,100
GSE and Consumables Transport	€ 9,996	€ 19,992
Propellant Disposal and Propellant Drum Return	€ 0	€ 29,282
Grand Total (Euros)	**€ 167,813**	**€ 509,417**
Grand Total (US Dollars) 0.78 EUR/USD (Launch Campaign in July 2010)	**$215,144**	**$653,099**
Savings as compared to Hydrazine:	$437,955	(over 2/3 cost reduction)

Summary of Observations

- Biggest environmental cost drivers over the life cycle of the propellant are facility operations and maintenance, transportation, and end of life disposal

- Costs associated with health and human safety protection while operating with hazardous materials are major cost drivers for propellant selection

- When environmental costs are included in the analysis, one can potentially bridge the gap between traditional investment and return on investment models in a timeframe that can be acceptable to investment decision-makers

- This research adds significant data to the full picture needed to complete the business case for green propulsion, however additional work is needed

December 7, 2012

QUESTIONS?

10th Annual Workshop on Environment and Alternative Energy

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